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(54) Measuring current

(57) To measure the current (It) flowing in a conductive track (1), the potential difference between two first contacts (5) is measured (13), and current (i) is supplied to the conductive track through two second contacts (4) to effect a predetermined change in the measured potential difference. The current (i) supplied to achieve the predetermined change in the measured potential difference is measured, and the current (It) through the track is calculated from the measured current (i) and the predetermined change in the potential difference. Fig 3 shows a two-contact probe having a first contact (23, 24) arranged within a second contact (22, 29) so as to resiliently telescope within the second contact when pressed against the conductive track.

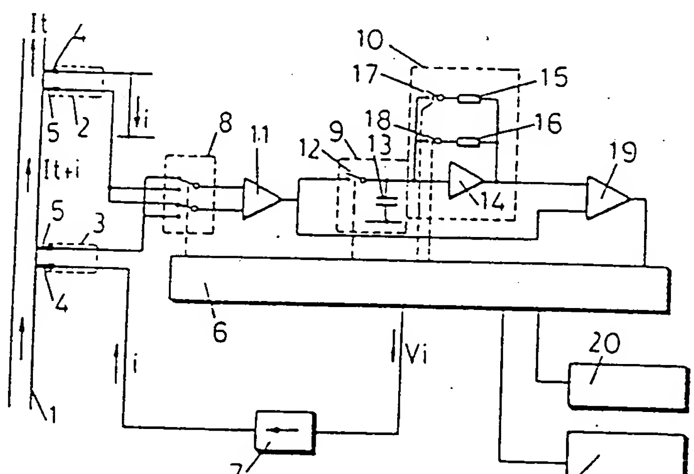

FIG.1

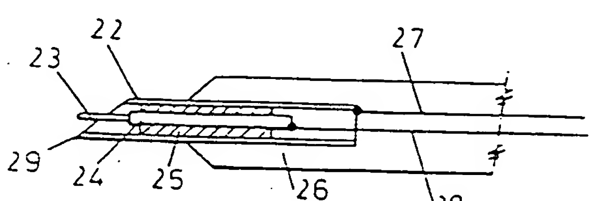

FIG.3

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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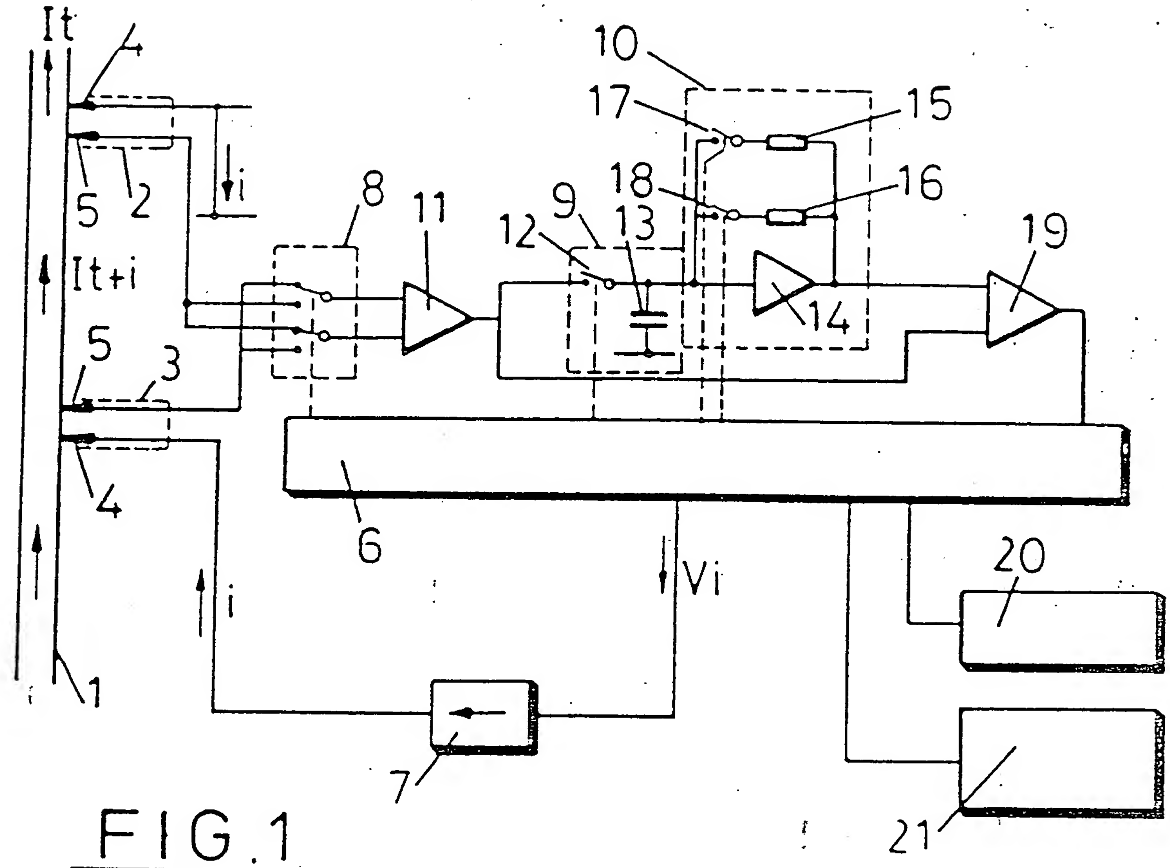

FIG.1

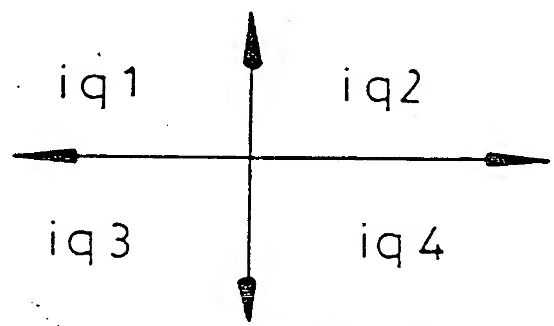

FIG.2

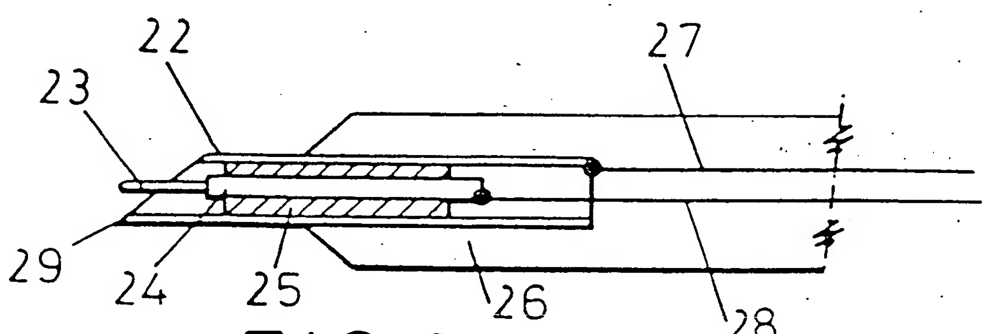

FIG.3

CURRENT MEASURING METHOD AND APPARATUS

The present invention relates to a current measuring method and apparatus.

There are many circumstances in which it is desired to measure small currents passing along conductive tracks without disrupting the operation of the circuits connected to those conductive tracks. For example it is desirable to be able to check the input and output currents on voltage regulators, find the magnitude and cause of fault currents on printed circuit boards, find the location of short circuits on printed circuit boards, measure current consumptions of individual devices in a circuit, check that low power devices are operating in their specification, check that "sleep" modes are operational on microprocessors, monitor charge and discharge currents on batteries, measure current flow down sections of backplane power busses, check currents taken by light emitting diodes, and confirm the readings of moving coil meters. It is of course a relatively simple matter to make current measurements if a device can be connected in series with the conductive track in which one is interested. Unfortunately this is often not possible without disrupting the conduit.

Current monitoring meters have been made available but generally suffer from insensitivity, low accuracy, or an inability to resolve between closely spaced tracks. There is clearly a need for a device which would enable a user to obtain a direct reading of current flow down a track with the same ease and accuracy as is the case when measuring voltages using a conventional digital volt meter.

It is an object of the present invention to provide an improved current measuring method and apparatus.

According to the present invention there is provided a current measuring apparatus comprising two probes adapted for positioning in contact with spaced apart regions of a conductive track, each probe having a first and a second contact, means for measuring the potential difference between the two first contacts, means for supplying current to the conductive tracks through the two second contacts to effect a predetermined change in the measured potential difference, means for measuring the supplied current, and means for calculating the current through the track before the track is contacted by the probes from the measured current and the predetermined change in potential difference.

The present invention also provides a method for measuring the magnitude of a current flowing down a conductive path, wherein two probes are positioned in contact with spaced apart regions of the conductive track, each probe comprising first and second electrically insulated contacts, the potential difference between the two first contacts is measured, current is supplied to the conductive track through the two second contacts to effect a predetermined change in the measured potential difference, the current supplied to achieve the predetermined change in the measured potential difference is measured, and the current through the track before the track was contacted by the probes is calculated from the measured current and the predetermined change in the potential difference.

The predetermined change in potential difference may be a percentage change selected to suit a particular measurement range.

Preferably each measurement is the result of a series of operations in which the current injected into the conductive track is reversed and the connection of the probes through the monitoring equipment is reversed thus giving a four stage cycle. This enables an average result to be produced which cancels out errors due to voltage offsets, thermal EMFs and noise.

The present invention also provides a double contact probe comprising a first tubular contact, and a second contact extending along the axis of the tubular contact, wherein the second contact is resiliently mounted within the first contact so as to be electrically isolated therefrom, the first contact extends to a pointed tip, the second contact when unrestrained extends to a point axially beyond the said pointed tip, and the resilient mounting of the second contact is such that a predetermined axial pressure on the second contact causes it to move axially into the first contact so that the tips of the two contacts will lie on the conductive track irrespective of the angle of approach of the probe.

Preferably the second contact is a spring-loaded telescopic assembly supported in a body of electrically insulating material within the first contact. The pointed tip of the first contact may be defined by cutting off the end of the first contact along a planar cut inclined to a plane perpendicular to the tube axis.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:-

Fig. 1 is a schematic illustration of an apparatus in accordance with the present invention;

Fig. 2 is a schematic illustration of a

switching cycle followed during operation of the system illustrated in Fig. 1, and

Fig. 3 is a schematic sectional illustration of a probe incorporated in the system of Fig. 1.

Referring to the drawings, Fig. 1 schematically illustrates a conductive track 1 along which a current It is passing. The track is contacted by two probes 2 and 3 each of which has a first contact 4 which is used to convey current to and from the track and a second contact 5 which is used to monitor the voltage on the track. The system to be described below injects a current i into the track so that the current between the probes is the sum of It and i.

A microprocessor control system 6 produces a control output voltage Vi which is applied to a voltage to current converter 7 the output of which controls the magnitude of the current i injected into the track. The control system also provides control inputs to an input reversal switch 8, a sample and hold circuit 9 and a variable gains stage 10.

The input reversal switch 8 simply enables the voltage derived from contacts 5 and applied to an input amplifier 11 to be reversed. That voltage is sampled in the sample and hold circuit by closing a switch 12 and charging a capacitor 13 to the sampled voltage.

The variable gain stage comprises an amplifier 14 with alternative feedback resistors 15 and 16 which are switched into circuit by respective switches 17 and 18. When switch 17 is closed the resistor 15 sets a predetermined percentage reduction in gain and when the switch 18 is closed the resistor 16 sets a predetermined percentage increase in gain.

The output of the amplifier 14 is applied to one terminal of a comparator 19 which also receives an input direct from the input amplifier 11. Thus the

comparator provides an output to the control system which is a function of the difference between the voltage sampled between the contacts 5 and the voltage output by the variable gain stage. The control system also provides outputs to a display 20 and is provided with front panel controls 21 for adjusting for example the measurement range.

The spacing between the contacts 4 and 5 of each probe is as small as is conveniently possible, for example 0.3175cm, and thus the spacing between the contacts is very much smaller than the spacing between the probes. One contact is used to inject current into the track and the other is used to measure the voltage on the track. This ensures accurate measurement of voltage and eliminates errors due to voltage drops and potential differences which would be caused by the presence of the injected current in a single contact probe.

The alternative feedback configurations of the variable gain stage 10 may be set to give equal but opposite changes in gain, that is one plus G percent and one minus G percent, G percent being a predetermined value determined by the characteristics of the system and varied according to which current range is selected. The comparator 19 may be set up to indicate to the control system when its inputs are equal. The basic operational technique is to accurately measure the potential difference between the voltage contacts 5, and then to modify this potential difference by a known amount by injecting a small current via the current contacts 4. This injected current is measured and then used to calculate the original track current.

In order to obtain each reading which is output to the display 20, a cycle of operations occurs.

This cycle is described with reference to Fig. 2. In each cycle, measurements are taken of the track current in four modes, or quadrants (i q1-4) and the final measured track current It is computed from these four measurements.

Referring to Fig. 2, in quadrant q1 the injected current i is selected so as to increase the measured potential difference and thus cause an increase in voltage Vm. In quadrant q2, the injection current i is caused to reduce the measured potential difference by minus Vm. In quadrant q3 the input switch 8 is reversed and the injection current i is selected to cause an increase in potential difference of plus Vm. In quadrant q4, the input switch 8 is still reversed but the injection current i is selected to cause a reduction in the measured potential difference of minus Vm. Thus the top half of Fig. 2 represents the input switch 8 in its "normal" condition and the bottom half indicates the input switch in its reversed condition. The left-hand side of Fig. 2 indicates the selected of an injection current to cause an increase in the measured potential difference and the right-hand side of Fig. 2 indicates the selection of an injection current to cause a reduction in the measured potential difference.

Within each of the four quadrants, a similar series of operations occurs. In the case of quadrant q1, these operations are as follows:

1. with the input switch 8 in its normal condition, and with no injection current (thus i equals zero), the value of the potential difference between the voltage contacts 5 is measured. This voltage is referred to hereinafter as voltage Vo.

2. the voltage Vo is stored in the sample and hold circuit 9.

3. the variable gain stage 10 is set to give a gain of 1 + G percent. Thus the voltage Vo, increased by G percent, appears at the upper input of comparator 19 (Fig. 1).

4. the control system 6 causes a current i to be injected into the track 1, the injected current modifying the potential difference measured by the voltage contacts so as to produce a voltage at the lower input to comparator 19 which equals the voltage at the upper input comparator 19. This balancing of voltage levels at the two inputs to the comparator 19 uses a successive approximation technique to obtain a high resolution whilst maintaining speed and stability.

5. the value of the injected current which causes the voltage levels at the two inputs of the comparator 19 to be equal is stored in memory as (i q1).

A similar series of steps is carried out in each of the four quadrants. Thus to obtain (i q2), the variable gain stage 10 is reset to give a gain of one minus G percent and steps 4 and 5 above are repeated. (i q3) is obtained by reversing the input switch 8 and setting the gain to 1 plus G percent and (i q4) is obtained by keeping the input switch 8 reversed and setting the gain to 1 minus G percent.

The four values (i q1), (i q2), (i q3), and (i q4) are averaged to produce a final single value Ia. This averaging ensures that all errors due to offsets, thermal EMFs and general noise are cancelled out.

The value of the track current It is now calculated in the control system from the following formula:

(track current)= 100 (average current)/(gain percent)

that is:

$$It = 100Ia/G$$

For example, if G = 20 percent, then the injected current i will be that required to modify the original current by 20 percent. Therefore the original track current It must be 100/20 times larger, that is 5 times larger.

In principle, the larger the value of G, the greater the injected current must be and the greater will be the accuracy of the result. However if currents up to 2 amps are to be measured, then G needs to be small in order to keep current consumption in the monitoring circuit as low as possible, and to avoid the problems of accurate and fast control of high currents. With this in mind, a different value of G is selected for each of a series of ranges e.g. 0 to 2 amps, 0 to 200 Ma 0 to 20 Ma etc. A relatively high value of G is used for low current ranges, where high resolution is required, and lower values of G are used for high current ranges to avoid high injection currents whilst maintaining adequate resolution.

The circuitry schematically illustrated in Fig. 1 can be made up from any suitable circuit. By way of example however, the input reversal switch 8 will be an electronically controlled CMOS analog switch such as type DG211, DG411 or DG441. The input amplifier 11 may be a single ended input amplifier such as the OP-77 operational amplifier device. The sample and hold circuit 9 may comprise a CMOS input switch 12 such as a DG211 or similar and the capacitive holding circuit itself may be of a standard configuration incorporating a low leakage capacitor followed by a high input impedance operational amplifier such as an OP-77.

The variable gain stage may consist of OP-77 amplifiers with the feedback resistor network

switches 17 and 18 being CMOS analog switches such as DG211. The control system comprises a conventional microprocessor and associated circuitry capable of interfacing with the other elements of the system and of performing the necessary computation. Typical configurations will include a 6303 processor, EPROM interface latches and clock circuitry. The voltage to current converter 7 which converts a digital output from the control system 6 into the injection current may comprise a conventional configuration of a digital to analog converter (such as a DAC0800) and a high current output operational amplifier such as the L272. The display device 20 may be any appropriate device, such as a three and a half digit LCD or LED, and the appropriate display driver e.g. a 7211 device.

It is important that the probes 1 and 2 are sufficiently small as to enable reliable contacts to be made with fine circuit tracks. Fig. 3 illustrates one such probe device.

Referring to Fig. 3, the illustrated probe comprises a first tubular contact 22 which corresponds to the current contact 4 of Fig. 1. A second contact 23 which corresponds to the voltage contact 5 of Fig. 1 is supported so as to extend along the axis of the tubular first contact 22. The first contact 23 has a tip which projects axially beyond the end of the tube 22 when unrestrained, the contact 23 being telescopically mounted in a conductive housing 24 which is secured within an insulating body 25 within the tube 22. A pen like body 26 supports the contact assembly and conductors 27 and 28 extend through the body 26 for connection to the circuit components illustrated in Fig. 1.

The end of the tubular contact 22 is cut off at

an angle inclined to a plane perpendicular to the tube axis so as to define a pointed tip 29. The end of the second contact 23 normally projects beyond the tip 29 but when axial pressure is applied to the first contact 23 it retracts into the telescopic housing 24 until the tip 29 comes up against the same obstruction as that applying axial pressure to the first contact 23. Thus the resilience of the second contact 23 provides a positive fixed reaction to the users hand pressure and the two contacts automatically make good contact with a conductive track against which the probe is pressed regardless of the angle of the axis of the probe relative to the conductive track. Thus a highly compact and rugged structure is provided in which the spacing between the second contact 23 and the tip 29 of the first contact can be relatively small, for example 0.3175cm.

CLAIMS

1. A current measuring apparatus comprising two probes adapted for positioning in contact with spaced apart regions of a conductive track, each probe having a first and a second contact, means for measuring the potential difference between the two first contacts, means for supplying current to the conductive tracks through the two second contacts to effect a predetermined change in the measured potential difference, means for measuring the supplied current, and means for calculating the current through the track before the track is contacted by the probes from the measured current and the predetermined change in potential difference.

2. A method for measuring the magnitude of a current flowing down a conductive path, wherein two probes are positioned in contact with spaced apart regions of the conductive track, each probe comprising first and second electrically insulated contacts, the potential difference between the two first contacts is measured, current is supplied to the conductive tract through the two second contacts to effect a predetermined change in the measure potential difference, the current supplied to achieve the predetermined change in the measured potential difference is measured, and the current through the track before the track was contacted by the probes is calculated from the measured current and the predetermined change in the potential difference.

3. A method according to claim 2, wherein the predetermined change in potential difference is a percentage change selected to suit a particular measurement range.

4. A method according to claim 2 or 3, wherein each measurement is the result of a series of operations in which the current injected into the conductive track is reversed and the connection of the probes through the monitoring equipment is reversed in a four stage cycle, whereby an average result is produced which cancels out

errors.

5. A double contact probe comprising a first tubular contact, and a second contact extending along the axis of the tubular contact, wherein the second contact is resiliently mounted within the first contact so as to be electrically isolated therefrom, the first contact extends to a pointed tip, the second contact when unrestrained extends to a point axially beyond the said pointed tip, and the resilient mounting of the second contact is such that a predetermined axial pressure on the second contact causes it to move axially into the first contact so that the tips of the two contacts will lie on the conductive track irrespective of the angle of approach of the probe.

6. A double contact probe according to claim 5, wherein the second contact is a spring-loaded telescopic assembly supported in a body of electrically insulating material within the first contact.

7. A double contact probe according to claim 6, wherein the pointed tip of the first contact is defined by cutting off the end of the first contact along a planar cut inclined to a plane perpendicular to the tube axis.

8. A current measuring apparatus substantially as hereinbefore described with reference to the accompanying drawings.

9. A current measuring method substantially as hereinbefore described with reference to the accompanying drawings.

10. A double contact probe substantially as hereinbefore described with reference to the accompanying drawings.

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